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Method for Dynamically Adjusting a Target Load for a Reverse Link Channel in a CDMA Network

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METHOD FOR DYNAMICALLY ADJUSTING A TARGET LOAD FOR A REVERSE LINK CHANNEL IN A CDMA NETWORK

BACKGROUND OF THE INVENTION

In CDMA networks, the mobile stations share a reverse link channel and may transmit simultaneously. During transmission, each mobile station spreads its transmitted signal with a spreading code selected from a set of mutually orthogonal spreading codes. The base station is able to separate the signals received from the mobile stations by a correlation process. For example, if the base station desires to receive the signal transmitted by mobile station A, the base station correlates the received signal to the spreading code used by mobile station A to despread the signal from mobile station A. All other signals will appear as noise due to lack of correlation. The base station can despread signals from all other mobile stations in the same manner.

CDMA networks are interference-limited systems. Since all mobile stations operate at the same frequency, internal interference generated within the network plays a critical role in determining system capacity and signal quality. The transmit power from each mobile station contributes to the noise floor and needs to be controlled to limit interference while maintaining desired performance objectives, e.g., bit error rate (BER), frame error rate (FER), capacity, dropped-call rate, coverage, etc. If the noise floor is allowed to get too high, widespread outages may occur. An outage is considered to occur when the power required to maintain minimum signal quality standards is greater than the maximum transmit power of the mobile station.

Rate control is one technique used to control the load on a reverse link channel in a CDMA network. In general, the transmit power required to maintain a desired signal quality increases as the data rate for transmission increases, and decreases as the data rate for transmission decreases. Thus, base station may control the reverse link load by

controlling the data transmission rates of the mobile stations transmitting on the reverse link channel.

A variety of rate control techniques are known for controlling the data transmission rates of mobile stations on a reverse link channel. Known rate control techniques include common rate control, dedicated rate control, and scheduling. The goal of all of the above described rate control techniques is to maintain the reverse link load at a desired target load chosen such that the frequency of outages is below some predetermined amount, e.g. 1%. The actual reverse link load will fluctuate around the target load. If the target load is set too high, the frequency of outages may exceed the desired amount resulting in poor perceived quality of serve (QoS). On the other hand, if the target load is set too low, system thoughput is diminished. Therefore, the target load reflects a balance between system QoS objectives and system throughput.

In systems using rate control for reverse link channels, it is desirable to dynamically adjust the target load. When the target load is fixed, the target load must be conservatively set to a value that will meet the desired QoS objectives under the poorest anticipated conditions. Setting the target load to a fixed value reduces the throughput that could be obtained under more favorable conditions. If the target load could be adjusted, the target load could be moved closer to the maximum load when the fluctuations in the reverse link load are small to increase system throughput while conditions are advantageous. Conversely, when the fluctuations are large, the target load could be adjusted downward to maintain the QoS objectives. Thus, by dynamically adjusting the target load, system throughout can be increased as compared to systems where the target load is fixed.

SUMMARY OF THE INVENTION

The present invention relates to a method and apparatus for dynamically adjusting the target load used by the base station for rate control. The base station periodically adjusts the target load to maintain a desired target frame error rate. The target frame error rate may be a frame error rate at a base station controller after frame selection. Alternatively, the target frame error rate may be a frame erasure rate at the base station.

In some embodiments, the base station computes a ratio of the measured frame erasure rate at the base station to a target frame erasure rate and calculates an adjustment factor based on the ratio. In other embodiments of the invention, the base station compares the measured frame erasure rate to a target frame erasure rate and increments or decrements the target load by fixed amounts depending upon the outcome of the comparison. Different target frame error rates for different groups of mobile stations may be taken into account in calculating the target load.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram of an exemplary wireless communication network according to one or more embodiments of the present invention.

Fig. 2 is a diagram of exemplary functional details for a radio base station according to the present invention.

Fig. 3 is a diagram illustrating a load curve for a reverse link channel in a CDMA network.

DETAILED DESCRIPTION OF THE INVENTION

Turning to the drawings, Fig. 1 illustrates an exemplary wireless communication network 10 in which the present invention may be implemented. Network 10 may be any

packet-switched communication network, for example, cdma2000 wireless network according to the IS-2000/2001 families of standards. However, those skilled in the art will appreciate that the wireless communication network may be configured according to other standards, including Wideband CDMA (WCDMA) standards.

Network 10 includes a Packet-Switched Core Network (PSCN) 20 and a Radio Access Network (RAN) 30. The PSCN 20 provides connection to one or more Public Data Networks (PDNs) 50, such as the Internet. The PSCN 20 includes a packet data serving node (PDSN) 22, a gateway 24, and an IP network 26. The details of the PSCN 20 are not material to the present invention and, therefore, the PSCN 20 is not discussed further herein. The RAN 30 provides the radio interface between the mobile stations 100 and the PCSN 12. An exemplary RAN 30 comprises a Packet Control Function (PCF) 32, one or more Base Station Controllers (BSC) 34, and a plurality of Radio Base Stations (RBSs) 36. BSCs 34 connect to the RBSs 36 to the PCF 32. Mobile stations 100 communicate with the RBSs 36 via the air interface as defined by the appropriate network standards, such as the IS-2000 family of standards.

Fig. 2 illustrates a functional diagram of an exemplary RBS 36 according to one embodiment of the present invention. It will be appreciated that the present invention is not limited to the RBS architecture illustrated in Fig. 2, and that other RBS architectures are applicable to the present invention. The functional elements of Fig. 2 may be implemented in software, hardware, or some combination of both. For example, one or more of the functional elements in RBS 36 may be implemented as stored program instructions executed by one or more microprocessors or other logic circuits included in RBS 36.

As shown in Fig. 2, RBS 36 includes transmitter circuits 38, forward link signal processing circuits 40, receiver circuits 42, reverse link signals processing circuits 44, and control and interface circuits 46. The transmitter circuits 38 include the necessary

RF circuits, such as modulators and power amplifiers, to transmit signals to mobile stations 100. The forward link signal processing circuits 40 process the signals being transmitted to the mobile stations 100. Forward link signal processing may include digital modulation, encoding, interleaving, encryption, and formatting. The receiver circuits 42 comprise the RF components, such as a receiver front end, necessary to receive signals from the mobile stations 100. Reverse link processing circuits 44 process the signals received from the mobile stations 100. Reverse link processing may include, for example, digital demodulation, decoding, de-interleaving, and decryption. Control and interface circuits 46 coordinate the operation of the RBS 36 and the mobile stations 100 according to the applicable communication standards and interface the RBS 36 with the BSC 34. The forward link processing circuits 40, reverse link processing circuits 44, and control and interface circuits 46 may be integrated in a single processor, or may be implemented in multiple processors, hardware circuits, or a combination of processors and hardware circuits.

A plurality of mobile stations 100 communicates with the RBS 36 over a reverse link channel. RBS 36 controls the data transmission rate of the mobile stations 100 transmitting on the reverse link channel to maintain the reverse link load at a desired target load L_T. Fig. 3 illustrates an exemplary load curve for a reverse link channel. RBS 36 may employ any known techniques for rate control, including scheduling, dedicate rate control, or common rate control. According to the present invention, the RBS 36 periodically adjusts the target load L_T to maximize throughput while maintaining a desired quality of service (QoS) objective. In one embodiment of the invention, the RBS 36 adjusts the target load L_T to provide a frame error rate (FER) of approximately 1% after frame selection by the BSC 34.

In CDMA networks 10, the mobile stations 100 in soft handoff will have more than one RBS 36 in their active set. Thus, a frame transmitted by a given mobile station 100 in soft handoff will be received by two or more RBSs 36. If the received frame at an RBS 36 is decodable, the RBS 36 forwards the frame to the BSC. Thus, the BSC 34 may receive the same frame from multiple RBSs 36. When multiple copies of the same frame are received by the BSC 34, the BSC 34 selects the frame with the maximum reverse frame quality to forward to the PCF 32.

A frame erasure occurs when a frame received by an RBS 36 is not decodable. The RBS 36 signals the BSC 34 when a frame erasure occurs. Even though a frame erasure may occur at one RBS 36, the BSC 34 may nevertheless receive the frame without error from another RBS 36. A frame error occurs when a frame transmitted by a mobile station 100 is not correctly received by any RBS 36. The term frame error rate (FER) as used in the description refers to the rate of frame errors at the BSC 34 to distinguish it from the frame erasure rate at the RBS 36. However, the term frame error rate as used in the claims should be broadly construed to include the frame erasure rate at the RBS 36.

From the foregoing, it is apparent that the frame erasure rate at the RBS 36 will typically be higher than the frame error rate (FER) after frame selection at the BSC 34. The ratio of the frame erasure rate at a given RBS 36 to the FER after frame selection at the BSC 34 will typically be in the order of five to one. This error ratio, denoted by the constant *c*, may be determined empirically from field data. If the target FER after frame selection at the BSC 34 is denoted by FER_T, the target frame erasure rate, denoted at the RBS 36 is given by:

$$\hat{\varepsilon} = c * FER_T , \qquad \text{Eq. 1}$$

where $\hat{\varepsilon}$ is the target frame erasure rate. In the various embodiments described below, the target frame erasure rate $\hat{\varepsilon}$ is used to periodically update the target load at the RBS 36.

The RBS 36 according to a first embodiment of the present invention uses the target frame erasure rate $\hat{\varepsilon}$ to periodically adjust the target load L_T used by the RBS 36 for rate control. In general, the RBS 36 attempts to maintain the average frame erasure rate at the RBS 36 for all mobile stations 100 as close as possible to the target frame erasure rate. The average frame erasure rate for RBS 36 at period *n* is denoted by $\varepsilon(n)$. During each control period, which is typically one frame, the RBS 36 counts the number of erased frames from all mobile stations 100 transmitting on the reverse link channel and divides the total number of erased frames by the total number of frames received to compute the average frame erasure rate $\varepsilon(n)$. The computation of the average frame erasure rate $\varepsilon(n)$ may exclude mobile stations 100 that are out of lock on the reverse link. The RBS 36 uses the average frame erasure rate $\varepsilon(n)$ to dynamically adjust the target load. Denoting the target load at period n as $L_T(n)$, the target load at period *n*+1 may be computed according to:

$$L_T(n+1) = \min\left\{L_{MAX}, \left(\alpha + (1-\alpha)\frac{\hat{\varepsilon}}{\varepsilon(n)}\right)L_T(n)\right\} \qquad \text{Eq. 2}$$

In Eq. 2, the term α alpha is a smoothing factor to smooth changes in the target load $L_T(n)$ in response to large fluctuations in the reverse link load. The term $\frac{\hat{\varepsilon}}{\varepsilon(n)}$ is the ratio of the target frame erasure rate to the measure frame erasure rate at time n. The target load is capped at some maximum load value L_{MAX}. In one exemplary embodiment of the invention, $\hat{\varepsilon} = 5\%$, $\alpha = 0.9$, and $L_{MAX} = 0.7$.

The RBS 36 adjusts the target load once per control interval, e.g., once per frame. If the average frame erasure rate $\varepsilon(n)$ at the RBS 36 increases, the ratio $\frac{\hat{\varepsilon}}{\varepsilon(n)}$ becomes smaller and the RBS 36 reduces the target load L_T to maintain the desired FER at the BSC 34. Conversely, if the frame erasure rate $\varepsilon(n)$ at the RBS 36 decreases, the ratio $\frac{\hat{\varepsilon}}{\varepsilon(n)}$ will become larger and the RBS 36 will increase the target load L_T to increase the system throughput. As noted above, the RBS 36 may use any known rate control techniques to increase or decrease the target load L_T, including scheduling, dedicated rate control, and common rate control.

In the embodiment described above, the magnitude of the changes in the target load L_T varies depending on the measured frame erasure rate at the RBS 36. In other embodiments, the magnitude of the changes in the target load L_T may be constrained to fixed step sizes. The step sizes may be different for increases and decreases in the target load L_T. Assume that a fixed step size $Step_D$ and $Step_U$ is defined for downward adjustments and upward adjustments respectively in the target load L_T. In a second embodiment of the present invention. The upward adjustments may be related to the downward adjustments by:

$$Step_U = \frac{Step_D}{\frac{1}{\hat{\varepsilon}} - 1} \qquad \text{Eq. 3}$$

The RBS 36 in the second embodiment compares the average frame erasure rate $\varepsilon(n)$ for all mobile stations 100 to the target frame erasure rate $\hat{\varepsilon}$. If $\varepsilon(n) > \hat{\varepsilon}$, the RBS 36 decreases the target load L_T by $Step_D$. Conversely, if $\varepsilon(n) < \hat{\varepsilon}$, the RBS 36 increases the target load L_T by $Step_U$.

A per user step size may be defined and used to calculate the changes to the target load L_T. Assume that fixed per user step sizes $Step_D$ and $Step_U$ are defined respectively for upward and downward adjustments to the target load for each user k in a third embodiment of the invention. $Step_D(k)$ and $Step_U(k)$ may be related as set forth in Eq. 3 above. The change Δ in the target load L_T may be calculated by:

$$\Delta = \sum_k \{FQI(k) * Step_U(k) - (1 - FQI(k)) * Step_D(k)\}, \qquad \text{Eq. 4}$$

where $FQI(k)$ is a frame quality indicator having a value of 1 for a good frame or 0 for a bad frame. In this example, the target load L_T is adjusted every frame according to:

$$L_T(n+1) = L_T(n) + \Delta a, \qquad \text{Eq. 5}$$

where *a* is a weighting factor. Note that $Step_D(k)$ and $Step_U(k)$ may be the same for all users, in which case $Step_D(k)$ and $Step_U(k)$ may be replaced by $Step_D$ and $Step_U$ in Eq. 5.

The methods described above can be modified to accommodate different target FERs for different mobile stations 100. Assume as in the previous embodiment that per user step sizes are defined and that the step size $Step_D$ for downward changes is the same for all mobile stations 100. Note that it is not required that the downward step size $Step_D$ be the same for all users. Different downward step sizes could be defined, for example, for different user classes. Further assume that the target FER for mobile station *k* corresponds to a target frame erasure rate $\hat{\varepsilon}(k)$ for the mobile station 100. The upward step size $Step_U$ for upward adjustments to the target load L_T may be calculated for each mobile station *k* according to:

$$Step_U(k) = \frac{Step_D}{\dfrac{1}{\hat{\varepsilon}(k)} - 1} \qquad \text{Eq. 6}$$

The changes to the target load L_T for RBS 36 may then be computed by summing the per user changes for all mobile stations 100. The calculation of the change Δ is given by Eq. 4 and the calculation of the new target load is according to Eq. 5.

The computed upward adjustment $Step_U$ from Eq. 6 may be larger by a significant amount than the configured downward adjustment $Step_D$. In order to avoid sharp increases in the target load L_T, the upward adjustment may be limited to a defined maximum adjustment.

Substituting Eq. 6 into Eq. 4, the calculation of the change in the target load becomes:

$$\Delta = \sum_k \left\{ \frac{\hat{\varepsilon}(k)}{1-\hat{\varepsilon}(k)} FQI(k) - (1 - FQI(k)) \right\} * Step_D$$

$$= \sum_k \left\{ \frac{FQI(k)}{1-\hat{\varepsilon}(k)} - 1 \right\} * Step_D \qquad \text{Eq. 7}$$

Substituting Eq. 7 into Eq. 5, the equation for the calculation of the new target load L_T becomes:

$$L_T(n+1) = L_T(n) + a \sum_k \left\{ \frac{FQI(k)}{1-\hat{\varepsilon}(k)} - 1 \right\} * Step_D \qquad \text{Eq. 8}$$

In the case where the target FER is the same for all mobile stations 100, Eq. 8 simplifies to:

$$L_T(n+1) = L_T(n) + a \sum_k \left\{ \frac{FQI(k)}{1-\hat{\varepsilon}} - N \right\} * Step_D\,, \qquad \text{Eq. 9}$$

where N is the total number of mobile stations 100 and $\hat{\varepsilon}$ is the target frame erasure rate for all mobile stations 100.

The RBS 36 may use the target load L_T for rate control. Any known rate control techniques may be used, including common rate control, dedicated rate control, and scheduling. In systems using three state common rate control, fixed offsets Δ_{MAX} and Δ_{MIN} may be used to determine the maximum load L_{MAX} and minimum load L_{MIN} from the target load L_T as shown in Fig. 3. The various techniques described herein could be modified to calculate a maximum load L_{MAX}, a minimum load L_{MIN}, or other load threshold.

The present invention may, of course, be carried out in other specific ways than those herein set forth without departing from the scope and essential characteristics of the invention. The present embodiments are, therefore, to be considered in all respects as illustrative and not restrictive, and all changes coming within the meaning and equivalency range of the appended claims are intended to be embraced therein.